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(54) **MAGNETIC MEMORY DEVICE**

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H01L 43/08 (2006.01)
H01L 43/10 (2006.01)
H01L 43/02 (2006.01)

(52) **U.S. Cl.**

CPC ***G11C 11/161*** (2013.01); ***H01L 43/02*** (2013.01); ***H01L 43/08*** (2013.01); ***H01L 43/10*** (2013.01)

(58) **Field of Classification Search**

CPC H01L 43/12; H01L 43/08; H01L 43/10; H01L 27/228; H01L 29/82; G11C 11/161; H01F 10/126; H01F 10/3286; H01F 41/303; B82Y 40/00

USPC 257/421, 427; 438/3

See application file for complete search history.

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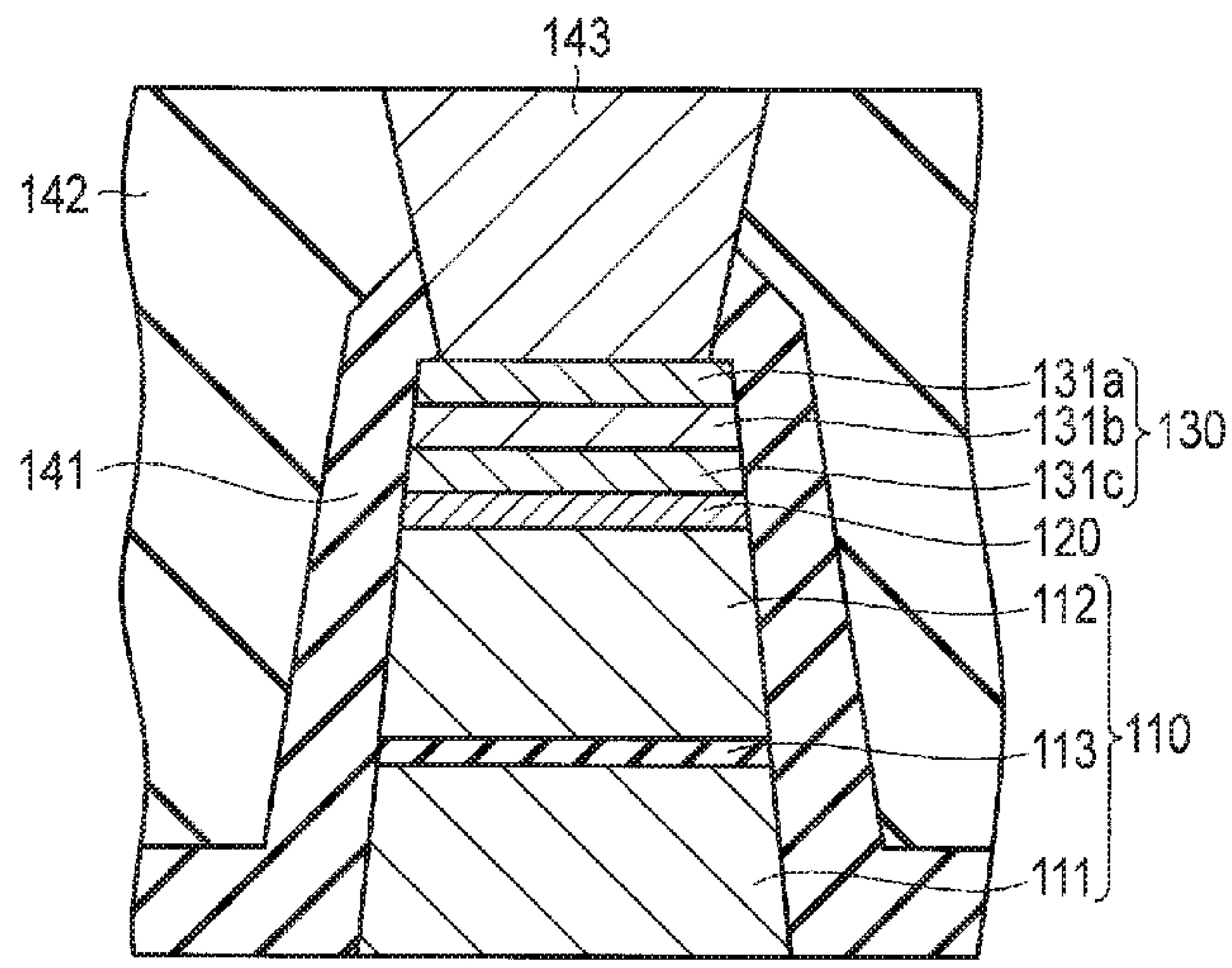
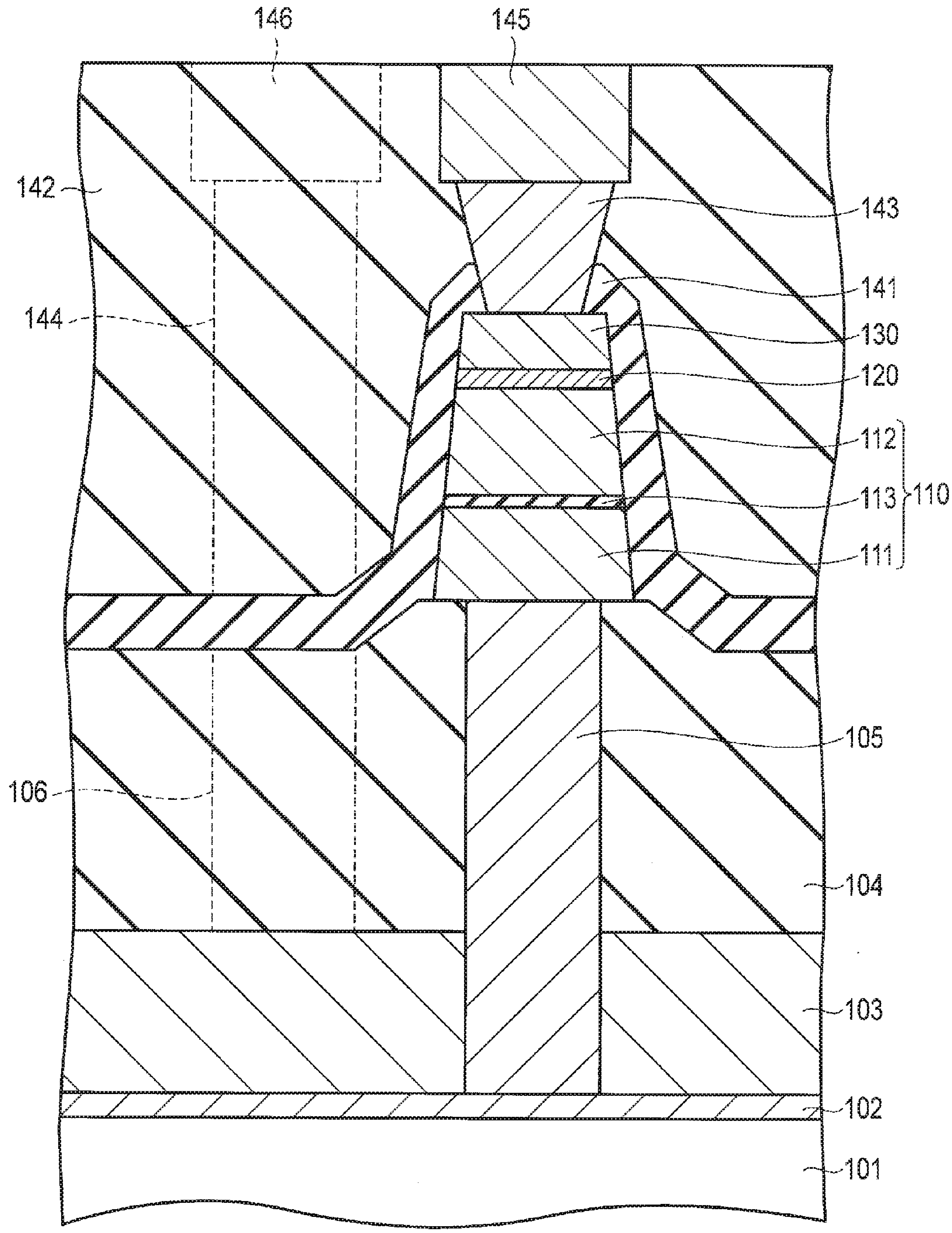
(57) **ABSTRACT**

According to one embodiment, a magnetic memory device includes a magnetoresistive effect element, and a first layer provided on the magnetoresistive effect element, wherein the first layer includes an upper conductive layer, and a predetermined metal containing conductive layer provided between the magnetoresistive effect element and the upper conductive layer and containing a predetermined metal selected from Pt, Ir, Pd and Au.

7 Claims, 6 Drawing Sheets

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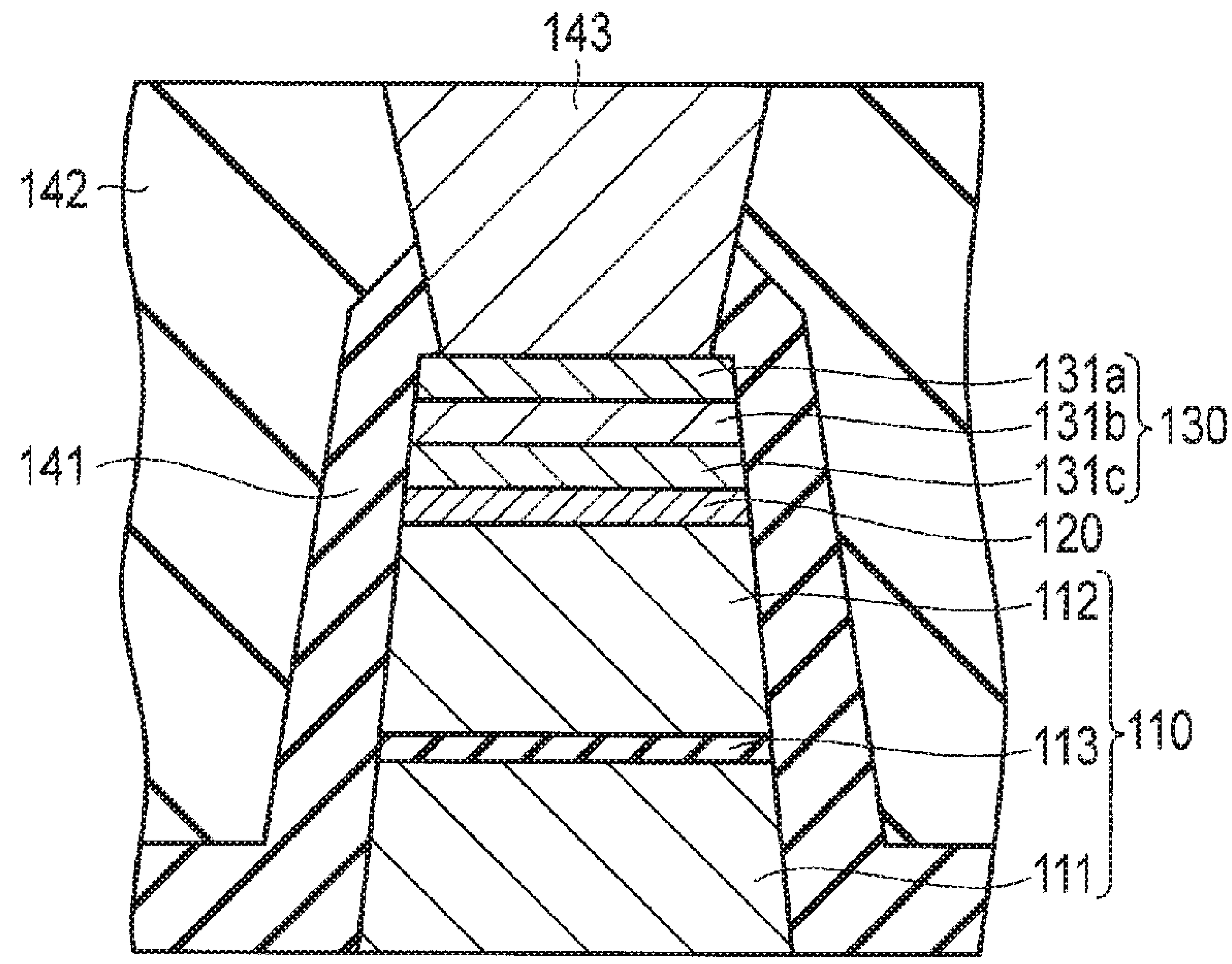
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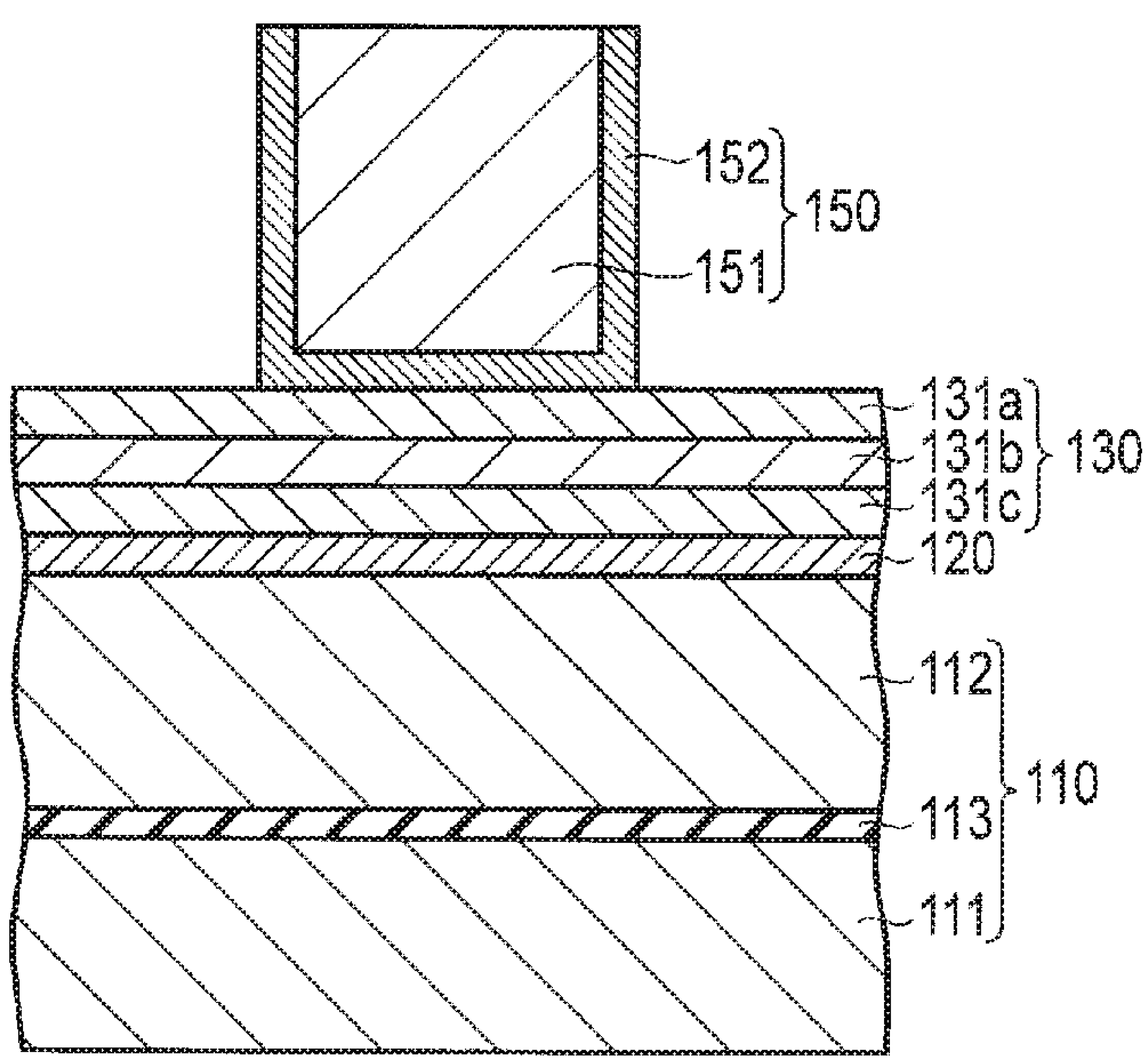
F I G. 2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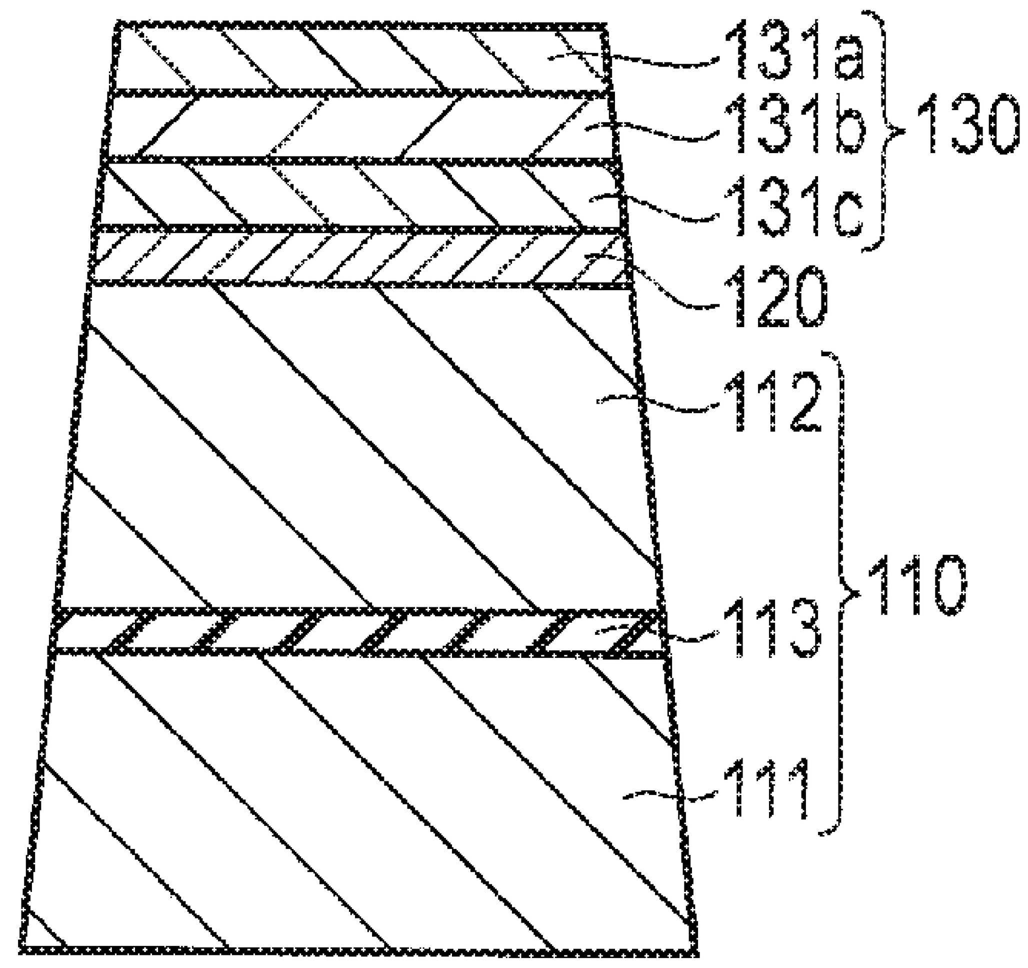
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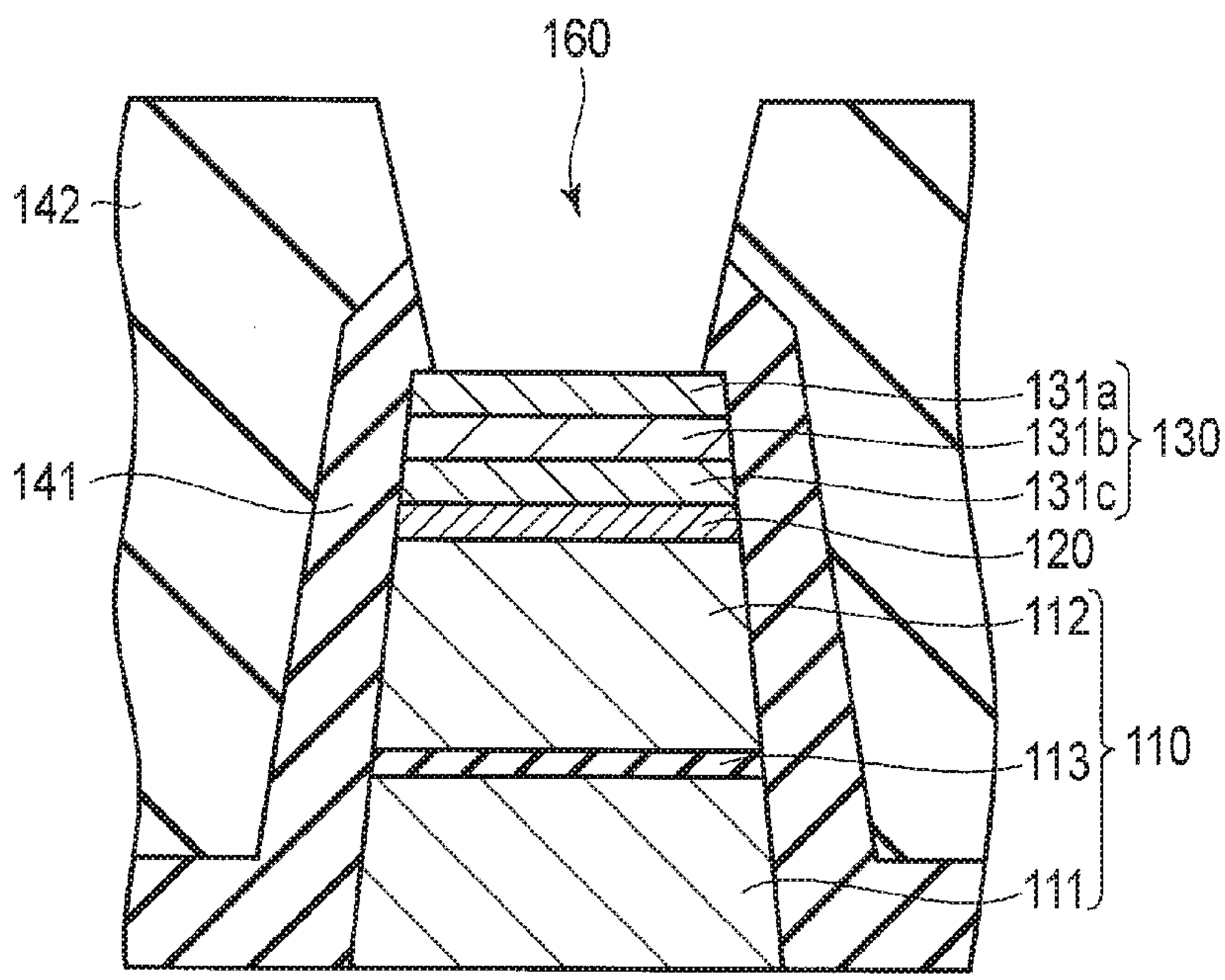
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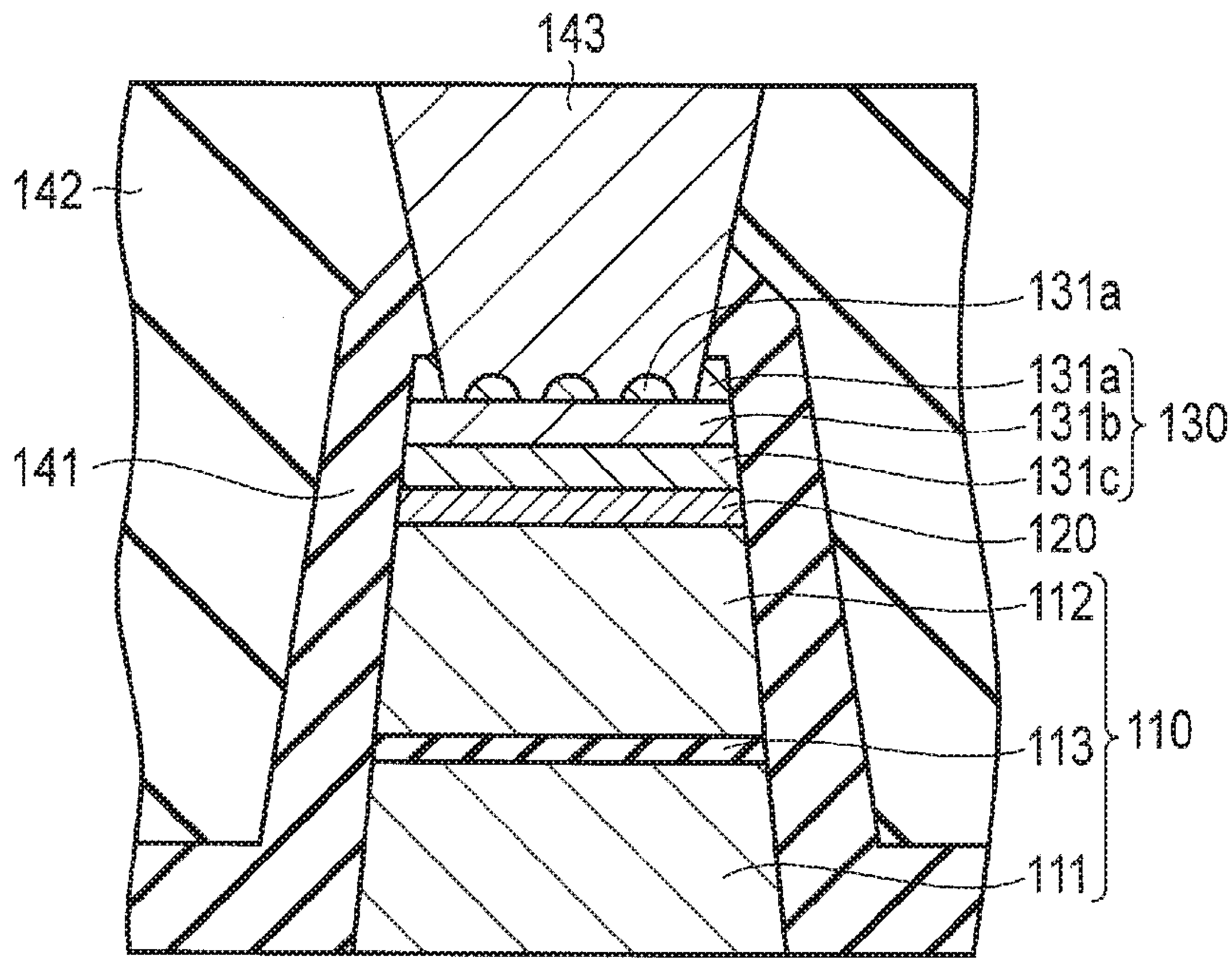
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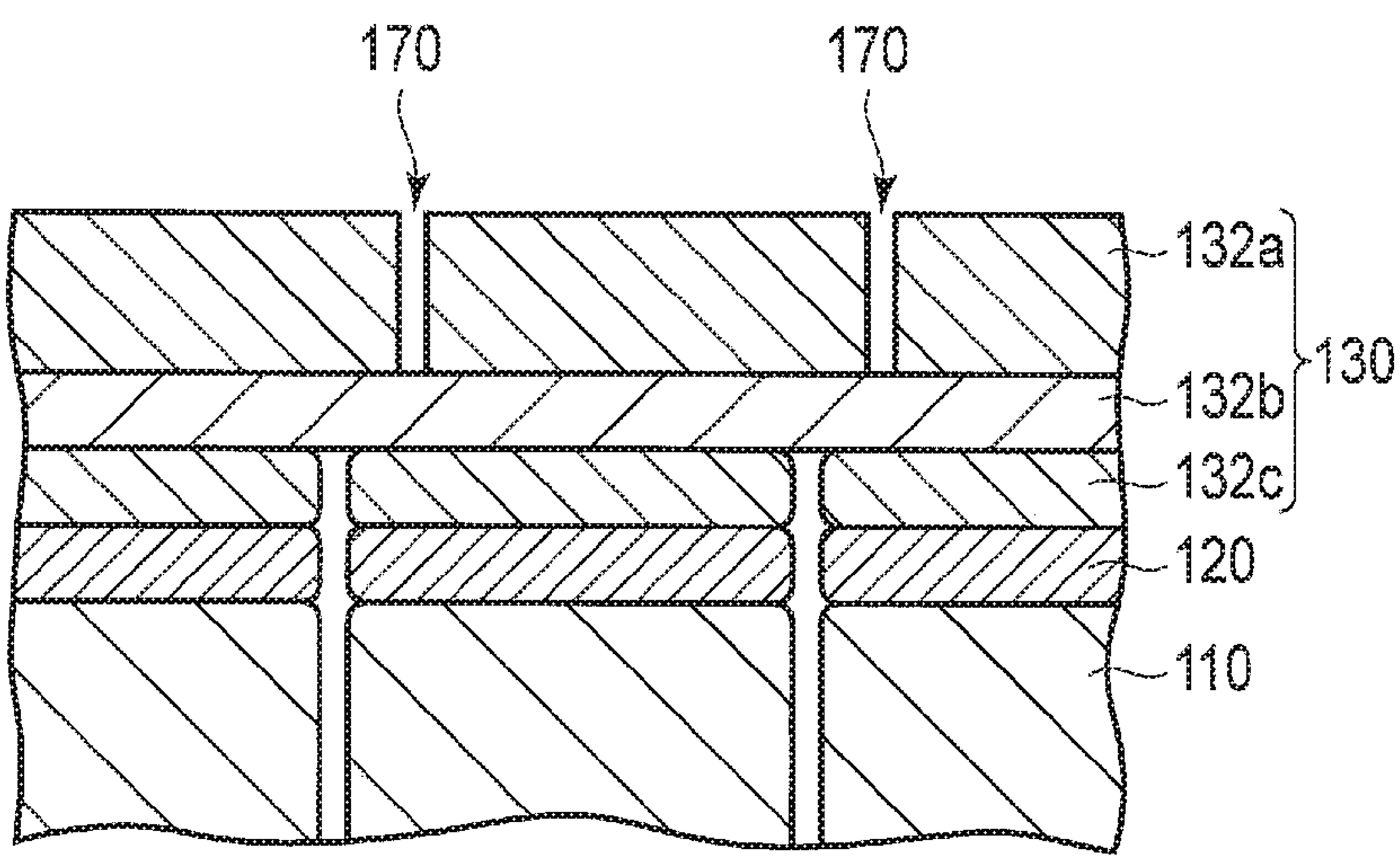
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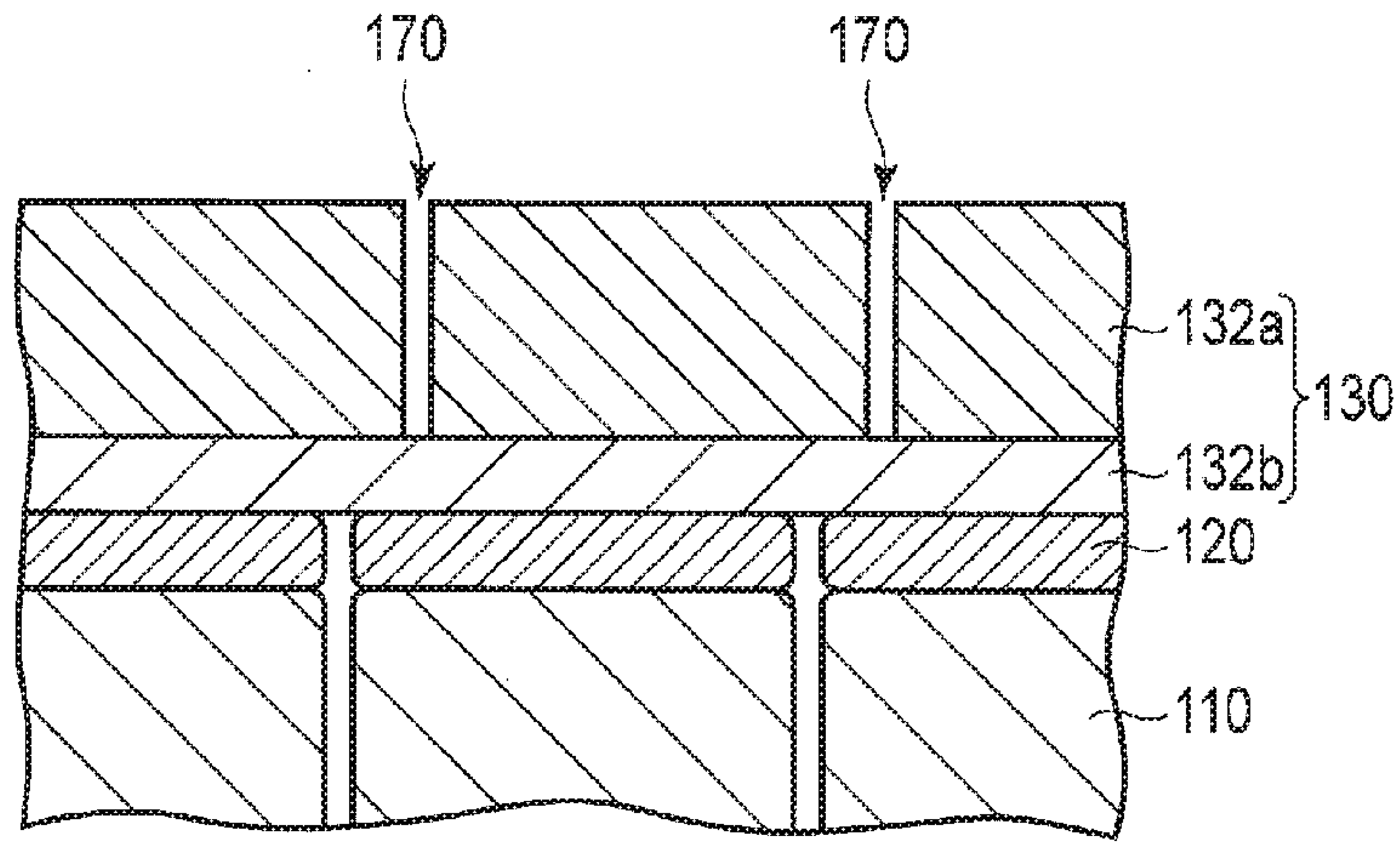
F I G. 7



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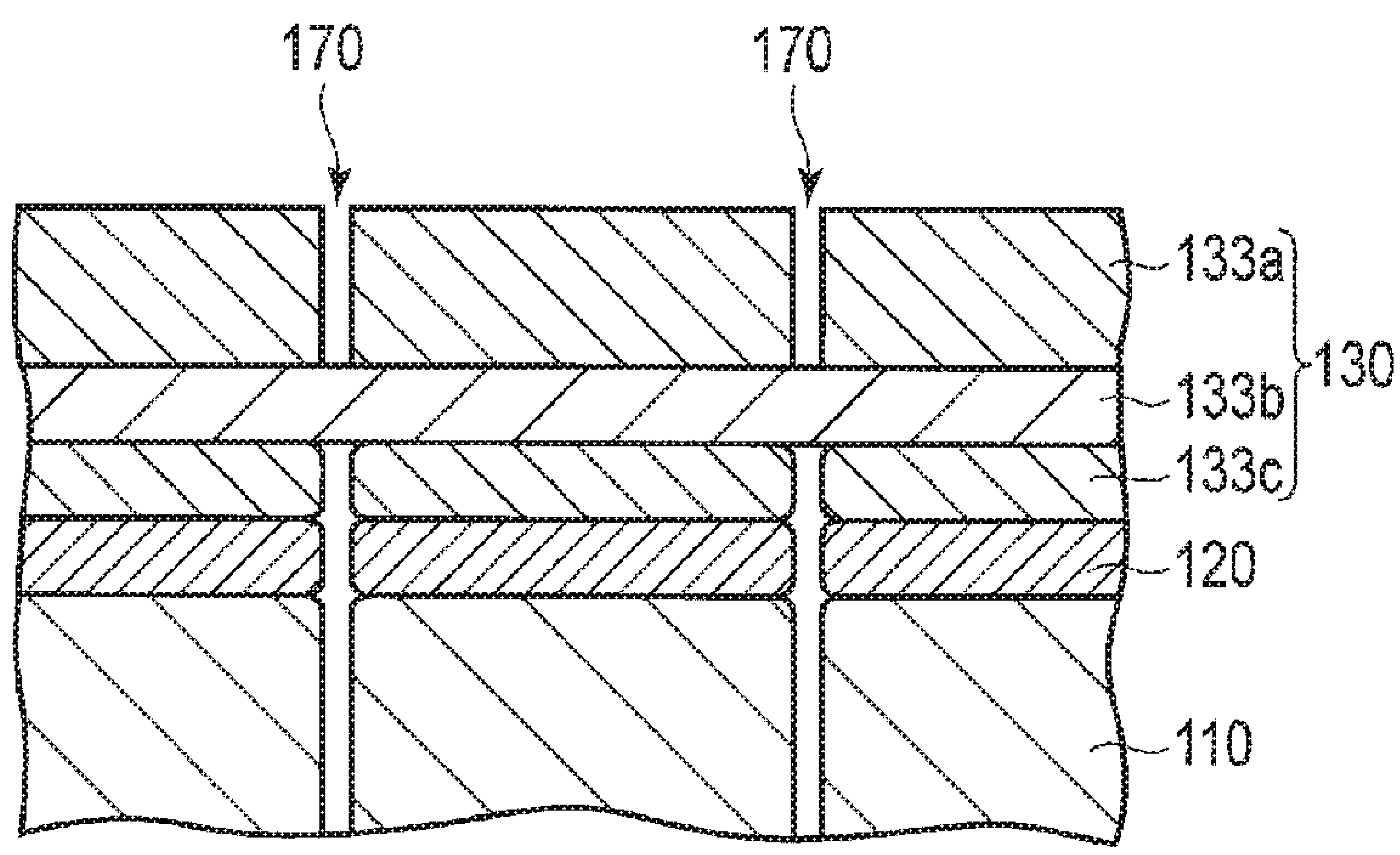

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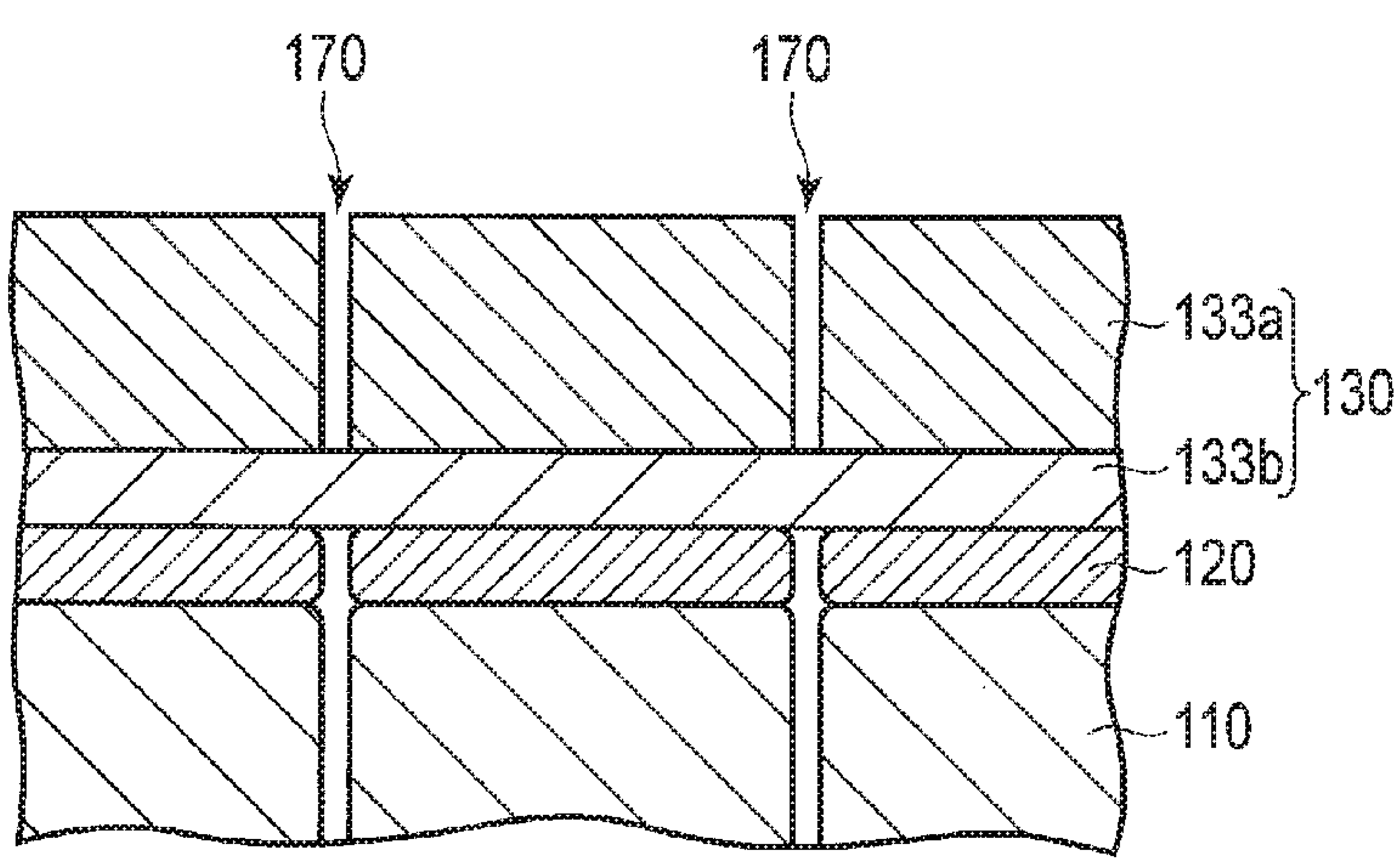

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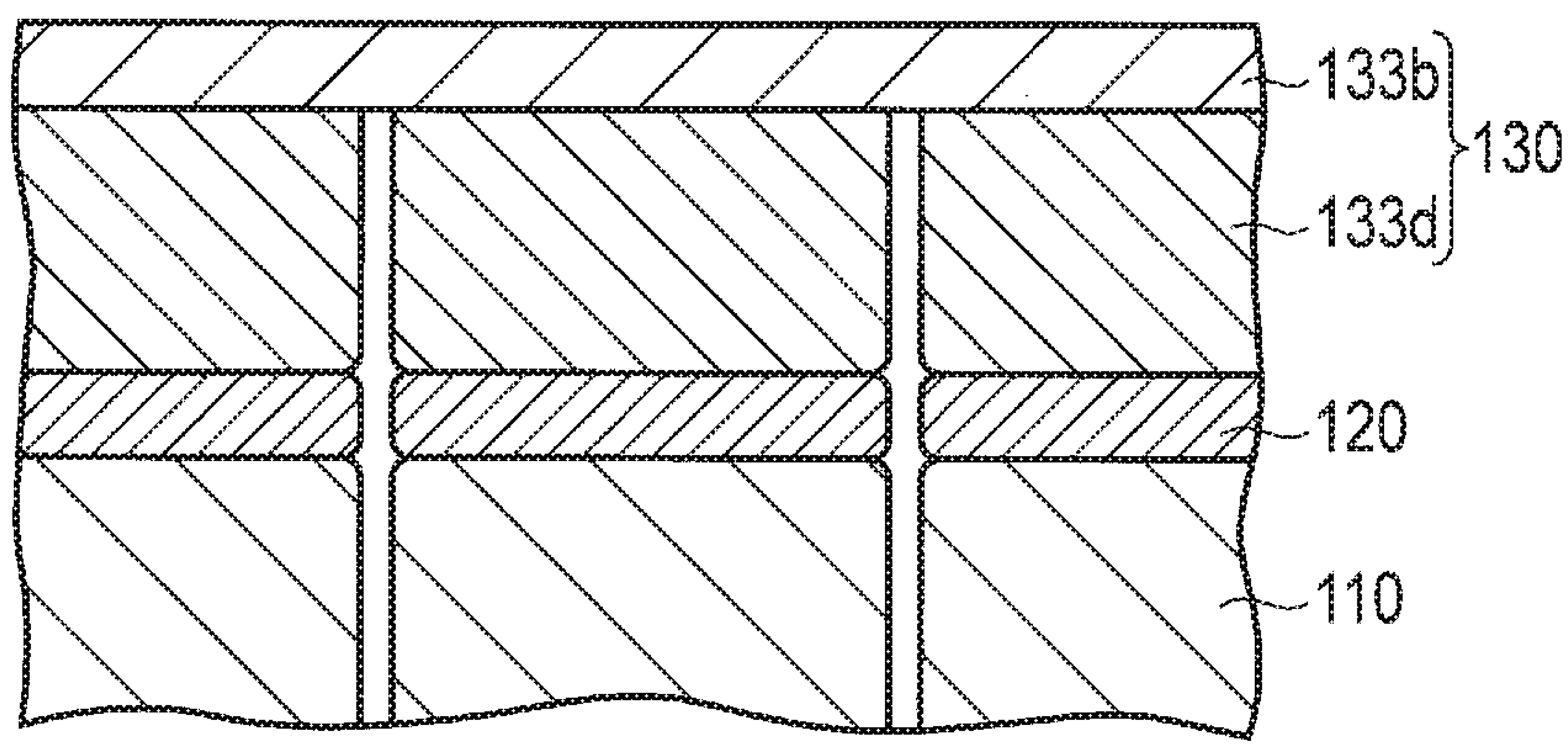
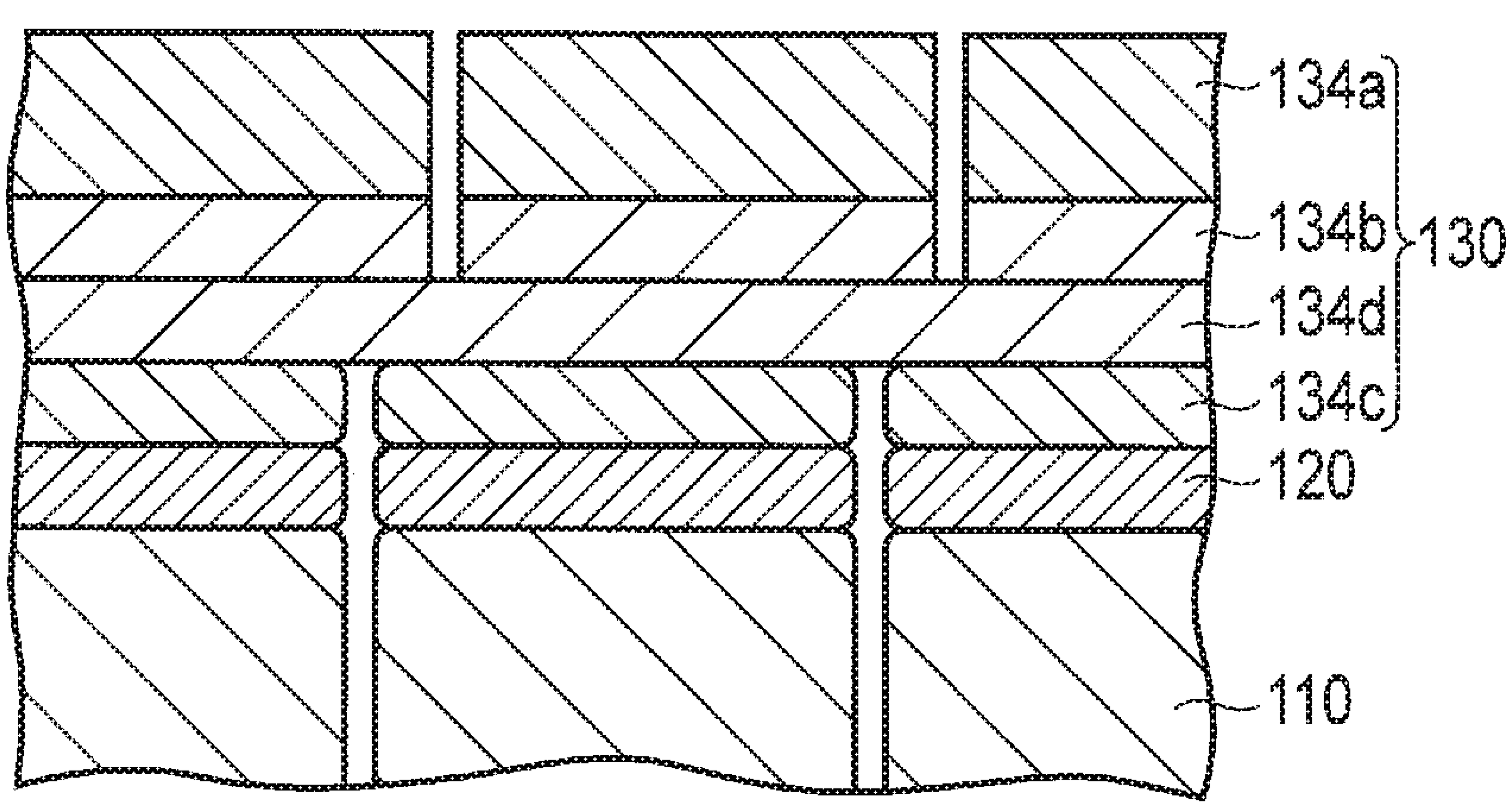


F I G. 11



F I G. 12

MAGNETIC MEMORY DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/185,318, filed Jun. 26, 2015, the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a magnetic memory device.

BACKGROUND

A magnetic memory device (semiconductor integrated circuit device) in which a magnetoresistive effect element and a transistor are integrated on the same semiconductor substrate is proposed. In such a magnetic memory device, a cap layer is generally provided on the magnetoresistive effect element.

Conventionally, however, a magnetic memory device equipped with a sufficiently reliable cap layer has not been necessarily achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view schematically showing a structure of a magnetic memory device of a first embodiment.

FIG. **2** is a cross-sectional view schematically showing a structure of a magnetoresistive effect element, a cap layer and the like of the magnetic memory device of the first embodiment.

FIG. **3** is a cross-sectional view schematically showing part of a method of manufacturing the magnetic memory device of the first embodiment.

FIG. **4** is a cross-sectional view schematically showing part of the method of manufacturing the magnetic memory device of the first embodiment.

FIG. **5** is a cross-sectional view schematically showing part of the method of manufacturing the magnetic memory device of the first embodiment.

FIG. **6** is a cross-sectional view schematically showing a structure of a modified example of the magnetic memory device of the first embodiment.

FIG. **7** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of a second embodiment.

FIG. **8** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of a modified example of the second embodiment.

FIG. **9** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of a third embodiment.

FIG. **10** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of a first modified example of the third embodiment.

FIG. **11** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of a second modified example of the third embodiment.

FIG. **12** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of a fourth embodiment.

DETAILED DESCRIPTION

In general, according to one embodiment, a magnetic memory device includes: a magnetoresistive effect element; and a first layer provided on the magnetoresistive effect element, wherein the first layer includes: an upper conductive layer; and a predetermined metal containing conductive layer provided between the magnetoresistive effect element and the upper conductive layer and containing a predetermined metal selected from Pt, Ir, Pd and Au.

Various embodiments will be described hereinafter with reference to the accompanying drawings.

Embodiment 1

FIG. **1** is a cross-sectional view schematically showing a structure of a magnetic memory device (semiconductor integrated circuit device) of a first embodiment.

A MOS transistor which functions as a select transistor for selecting a magnetoresistive effect element is formed in a surface region of a semiconductor substrate **101**. FIG. **1** shows source/drain regions **102** and a gate electrode (word line) **103** of the MOS transistor.

An interlayer insulating film **104** is formed on the semiconductor substrate **101** on which the MOS transistor is formed. Contact plugs **105** and **106** are provided in the interlayer insulating film **104**. Contact plug **105** is connected to one of the source/drain regions **102** and contact plug **106** is connected to the other of the source/drain regions **102**.

A spin transfer torque (STT) type magnetoresistive effect element **110** is provided on the interlayer insulating film **104**. The magnetoresistive effect element **110** includes a first magnetic layer (storage layer) **111** having variable magnetization, a second magnetic layer (reference layer) **112** having fixed magnetization and a nonmagnetic layer (tunnel barrier layer) **113** provided between the first magnetic layer **111** and the second magnetic layer **112**. The magnetoresistive effect element **110** is connected to contact plug **105**. The magnetoresistive effect element is also called a magnetic tunnel junction (MTJ) element.

When the direction of magnetization of the storage layer **111** is parallel to that of the reference layer **112**, the magnetoresistive effect element **110** shows a low-resistance state. When the direction of magnetization of the storage layer **111** is antiparallel to that of the reference layer **112**, the magnetoresistive effect element **110** shows a high-resistance state. Therefore, the magnetoresistive effect element **110** can store binary information (0 or 1) in accordance with the resistance state (low-resistance state and high-resistance state). The resistance state (low-resistance state and high-resistance state) can be set in accordance with a direction of a write current passing through the magnetoresistive effect element **110**.

A tungsten (W) layer **120** is formed on the magnetoresistive effect element **110**. A cap layer (first layer) **130** is formed on the W layer **120**. The cap layer **130** will be described later in detail.

The magnetoresistive effect element **110**, the W layer **120** and the cap layer **130** are covered with a protective insulating film **141**. An interlayer insulating film **142** is formed on the protective insulating film **141**. Contact plugs **143** and **144** are provided in the interlayer insulating film **142**. One end of contact plug **143** is connected to the cap layer **130** and the other end of contact plug **143** is connected to a bit line **145**. One end of contact plug **144** is connected to contact plug **106** and the other end of contact plug **144** is connected to a source line **146**.

FIG. **2** is a cross-sectional view schematically showing a structure of the magnetoresistive effect element **110**, the cap layer **130** and the like of the present embodiment.

As shown in FIG. **2**, the cap layer **130** is provided on the magnetoresistive effect element **110** with the tungsten (W) layer **120** between.

The cap layer (first layer) **130** includes an upper conductive layer **131***a*, a predetermined metal containing conductive layer **131***b* provided between the magnetoresistive effect element **110** and the upper conductive layer **131***a*, and a lower conductive layer **131***c* provided between the magnetoresistive effect element **110** and the predetermined metal containing conductive layer **131***b*.

The upper conductive layer **131***a* is formed of ruthenium (Ru). The lower conductive layer **131***c* is not limited, but is formed of ruthenium (Ru) in the present embodiment. The lower conductive layer **131***c* may be omitted.

The predetermined metal containing conductive layer **131***b* contains a predetermined metal selected from platinum (Pt), iridium (Ir), palladium (Pd) and gold (Au). More specifically, a Pt layer, an Ir layer, a Pd layer, an Au layer or an Ir oxide layer is used for the predetermined metal containing conductive layer **131***b*. These materials are superior in resistance to plasma gas, acid chemical solution and alkali chemical solution. Pt, Pd and Au are resistant to oxidizing. An oxide of Ir (Ir oxide) is conductive.

By thus providing the predetermined metal containing conductive layer **131***b* between the upper conductive layer **131***a* formed of Ru and the magnetoresistive effect element **110**, the magnetoresistive effect element **110** can be prevented from being exposed during the manufacturing process as described below.

FIG. **3**, FIG. **4** and FIG. **5** are cross-sectional views each schematically showing part of a method of manufacturing the magnetic memory device of the present embodiment.

First, as shown in FIG. **3**, a magnetoresistive effect element layer **110**, a tungsten (W) layer **120** and a cap layer **130** are sequentially formed on an underlying region (not shown) including a semiconductor substrate, a transistor and the like. After that, a hard mask **150** is formed on the cap layer **130**. The hard mask **150** is formed of a tungsten (W) layer **151** and a titanium nitride (TiN) layer **152**.

Next, as shown in FIG. **4**, a pattern of the magnetoresistive effect element **110** is formed by etching the cap layer **130**, the tungsten (W) layer **120** and the magnetoresistive effect element layer **110** by using the hard mask **150** as a mask. Ion beam etching (IBE) or reactive ion etching (RIE) is used for the etching. After the etching, the hard mask **150** is removed and the upper surface of the cap layer **130** is exposed.

Next, as shown in FIG. **5**, a protective insulating film **141** which covers the magnetoresistive effect element **110**, the tungsten (W) layer **120** and the cap layer **130** is formed. A silicon nitride film or an aluminum oxide film is used for the protective insulating film **141**. An interlayer insulating film **142** which covers the protective insulating film **141** is further formed. A silicon oxide film or the like is used for the interlayer insulating film **142**. After planarizing the interlayer insulating film **142**, a contact hole **160** is formed in the protective insulating film **141** and the interlayer insulating film **142** by RIE using a resist pattern (not shown) as a mask. The upper surface of the cap layer **130** is thus exposed. After that, the resist pattern is removed by ashing using gaseous oxygen, and wet cleaning is further performed.

Then, a contact plug **143** is formed in the contact hole **160**. For contact plug **143**, a W/TiN film, a Cu/Ta film or the like is used. The structure shown in FIG. **1** and FIG. **2** can be achieved by further forming a bit line, a source line and the like.

In the present embodiment, the upper conductive layer **131***a* is basically formed on the entire upper surface of the predetermined metal containing conductive layer **131***b* as shown in FIG. **2**. In the above manufacturing process, however, there is a possibility that Ru used for the upper conductive layer **131***a* is oxidized and part of the upper conductive layer **131***a* is removed when removing the resist pattern by ashing using gaseous oxygen. As a result, the upper conductive layer **131***a* may be formed on part of the upper surface of the predetermined metal containing conductive layer **131***b* as shown in FIG. **6**. In such a case, if the predetermined metal containing conductive layer **131***b* is not provided under the upper conductive layer **131***a*, the magnetoresistive effect element **110** may be damaged by a chemical solution for wet cleaning when performing the wet cleaning after the ashing.

In the present embodiment, the predetermined metal containing conductive layer **131***b* superior in resistance to plasma gas, acid chemical solution and alkali chemical solution is provided between the magnetoresistive effect element **110** and the upper conductive layer **131***a*. Therefore, invasion of the chemical solution for wet cleaning can be avoided by the predetermined metal containing conductive layer **131***b* even if part of the upper conductive layer **131***a* is removed.

In the above manufacturing process, part of the hard mask **150** may be left on the cap layer **130** when forming a pattern of the magnetoresistive effect element **110**, etc., by using the hard mask **150** as a mask. In such a case, W used for the hard mask **150** may be oxidized and a W oxide may be formed, which may increase contact resistance.

In the present embodiment, the predetermined metal containing conductive layer **131***b* is provided between the magnetoresistive effect element **110** and the upper conductive layer **131***a*. Therefore, the hard mask **150** can be completely removed. If the hard mask **150** is removed and the upper conductive layer (Ru layer) **131***a* is exposed during patterning (etching), part of the upper conductive layer **131***a* is also etched. Therefore, the hard mask **150** should preferably be removed completely right before the end of the patterning (etching). However, such etching control is difficult and part of the hard mask **150** may be left. In the present embodiment, the predetermined metal containing conductive layer **131***b* is provided under the upper conductive layer **131***a*. Accordingly, no problem occurs if the upper conductive layer **131***a* is somewhat etched. Therefore, the hard mask **150** can be reliably removed and the above problem can be avoided.

As described above, in the present embodiment, the predetermined metal containing conductive layer **131***b* is provided between the magnetoresistive effect element **110** and the upper conductive layer **131***a*. Therefore, the magnetoresistive effect element **110** can be reliably protected by the predetermined metal containing conductive layer **131***b* and a magnetic memory device equipped with a sufficiently reliable cap layer can be achieved.

Pt, Ir, Pd and Au contained in the predetermined metal containing conductive layer **131***b* are precious metals and are expensive. In the present embodiment, the predetermined metal containing conductive layer **131***b* is used for part of the cap layer. Therefore, the material cost can be reduced.

Embodiment 2

Next, the second embodiment is described. Since the basic structure and manufacturing method are similar to those of the first embodiment, the description of the matters described in the first embodiment is omitted.

FIG. **7** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of the present embodiment.

Similarly to the first embodiment, a cap layer **130** is provided on a magnetoresistive effect element **110** with a tungsten (W) layer **120** between.

In the present embodiment, the cap layer (first layer) **130** includes a first crystal conductive layer **132***a* having a crystal structure, an amorphous conductive layer **132***b* provided between the magnetoresistive effect element **110** and the first crystal conductive layer **132***a* and having an amorphous structure, and a second crystal conductive layer **132***c* having a crystal structure and provided between the magnetoresistive effect element **110** and the amorphous conductive layer **132***b*.

For example, Ru can be used for crystal conductive layers **132***a* and **132***c*. The material of the predetermined metal containing conductive layer **131***b* described in the first embodiment (i.e., Pt, Ir, Pd, Au or Ir oxide) may also be used for crystal conductive layer **132***a* and **132***c*. W or Ta may also be used.

The amorphous conductive layer **132***b* is formed of an amorphous metal described below.

As an amorphous metal for the amorphous conductive layer **132***b*, an amorphous alloy formed of a transition metal and a semimetal can be used. In this case, hafnium (Hf), iron (Fe), palladium (Pd), molybdenum (Mo), zirconium (Zr) or tantalum (Ta) is used as the transition metal. As the semimetal, phosphorus (P), boron (B), carbon (C), silicon (Si) or germanium (Ge) is used. For example, an amorphous alloy formed of about 80 at % transition metal and about 20 at % semimetal can be used. HfB and FeB can be typically used as the amorphous alloy.

In addition, an amorphous alloy formed of transition metals can also be used as the amorphous metal for the amorphous conductive layer **132***b*. In this case, a Cu—Zr alloy, an Fe—Zr alloy, an Ni—Nb alloy, a Ti—Ni alloy or the like can be used as the amorphous alloy.

In the present embodiment, damage to the magnetoresistive effect element **110** caused by a chemical solution and etching gas can be reduced by providing the amorphous conductive layer **132***b* between the magnetoresistive effect element **110** and crystal conductive layer **132***a*. This point is hereinafter described in detail.

Since an Ru layer or the like used for the cap layer **130** has a crystal structure, the magnetoresistive effect element **110** may be damaged by a chemical solution and etching gas invading through the crystal grain boundary **170**. In the present embodiment, the amorphous conductive layer **132***b* without a crystal grain boundary is provided between the magnetoresistive effect element **110** and crystal conductive layer **132***a*, invasion of the chemical solution and etching gas can be avoided by the amorphous conductive layer **132***b*.

Therefore, according to the present embodiment, the magnetoresistive effect element **110** can be reliably protected by the amorphous conductive layer **132***b* and a magnetic memory device equipped with a sufficiently reliable cap layer can be achieved.

FIG. **8** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of a modified example of the present embodiment.

Crystal conductive layer **132***c* is provided between the magnetoresistive effect element **110** and the amorphous conductive layer **132***b* in the above-described embodiment, but crystal conductive layer **132***c* is not provided in the modified example.

The same effect as the above-described embodiment can be achieved even by using the structure of the modified example.

Embodiment 3

Next, the third embodiment is described. Since the basic structure and manufacturing method are similar to those of the first and second embodiments, the description of the matters described in the first and second embodiments is omitted.

FIG. **9** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of the present embodiment.

Similarly to the first and second embodiments, a cap layer **130** is provided on a magnetoresistive effect element **110** with a tungsten (W) layer **120** between.

In the present embodiment, the cap layer **130** (first layer) includes a first crystal conductive layer **133***a* having a crystal structure, an amorphous conductive layer **133***b* having an amorphous structure, and a second crystal conductive layer **133***c* having a crystal structure. In the example shown in FIG. **9**, the amorphous conductive layer **133***b* is provided between the magnetoresistive effect element **110** and the first crystal conductive layer **133***a*, and the second crystal conductive layer **133***c* is provided between the magnetoresistive effect element **110** and the amorphous conductive layer **133***b*.

The amorphous conductive layer **133***b* contains a main element identical to that contained in crystal conductive layers **133***a* and **133***c*. The main element is selected from ruthenium (Ru), platinum (Pt), iridium (Ir), palladium (Pd), gold (Au), tungsten (W) and tantalum (Ta).

Crystal conductive layers **133***a* and **133***c* are formed mostly of the above element. More specifically, crystal conductive layers **133***a* and **133***c* are formed of an Ru layer, a Pt layer, an Ir layer, a Pd layer, an Au layer, a W layer, a Ta layer or an Ir oxide layer.

The amorphous conductive layer **133***b* is formed by forming a crystal conductive layer on the W layer **120** and then introducing a predetermined ion into part of the crystal conductive layer by ion implantation or IBE. That is, the crystal structure of the crystal conductive layer is collapsed by energy of the ion implantation or IBE and the amorphous conductive layer **133***b* without a crystal grain boundary can be achieved. Therefore, a basic constituent material of the amorphous conductive layer **133***b* is the same as that of crystal conductive layers **133***a* and **133***c*. An element (predetermined ion) used for the ion implantation or IBE is generally a noble gas element such as argon (Ar). Therefore, the amorphous conductive layer **133***b* also contains the noble gas element.

In the present embodiment, the amorphous conductive layer **133***b* without a crystal grain boundary is provided as part of the cap layer **130**. Accordingly, invasion of the chemical solution and etching gas from the crystal grain boundary **170** can be avoided by the amorphous conductive layer **133***b*.

Therefore, according to the present embodiment, the magnetoresistive effect element **110** can be reliably protected by the amorphous conductive layer **133***b* and a magnetic memory device equipped with a sufficiently reliable cap layer can be achieved.

FIG. **10** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of the first modified example of the present embodiment.

Crystal conductive layer **133***c* is provided between the magnetoresistive effect element **110** and the amorphous conductive layer **133***b* in the above-described embodiment, but crystal conductive layer **133***c* is not provided in the modified example.

The same effect as the above-described embodiment can be achieved even by using the structure of the first modified example.

FIG. **11** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of the second modified example of the present embodiment.

In the modified example, crystal conductive layer **133***d* is provided between the magnetoresistive effect element **110** and the amorphous conductive layer **133***b*. That is, the amorphous conductive layer **133***b* is provided as the uppermost layer of the cap layer **130**.

The same effect as the above-described embodiment can be achieved even by using the structure of the second modified example.

Embodiment 4

Next, the fourth embodiment is described. The structure of the present embodiment is based on a combination of the structure of the first embodiment and the structure of the second embodiment, or a combination of the structure of the first embodiment and the structure of the third embodiment. Since the basic structure and manufacturing method are similar to those of the first, second and third embodiments, the description of the matters described in the first, second and third embodiments is omitted.

FIG. **12** is a cross-sectional view schematically and mainly showing a structure of a cap layer of a magnetic memory device of the present embodiment.

Similarly to the first, second and third embodiments, a cap layer **130** is provided on a magnetoresistive effect element **110** with a tungsten (W) layer **120** between.

In the present embodiment, the cap layer **130** includes an upper conductive layer **134***a*, a predetermined metal containing conductive layer **134***b*, a lower conductive layer **134***c* and an amorphous conductive layer **134***d*. The upper conductive layer **134***a*, the predetermined metal containing conductive layer **134***b* and the lower conductive layer **134***c* correspond to the upper conductive layer **131***a*, the predetermined metal containing conductive layer **131***b* and the lower conductive layer **131***c* of the first embodiment, respectively. The amorphous conductive layer **134***d* corresponds to the amorphous conductive layer **132***b* of the second embodiment or the amorphous conductive layer **133***b* of the third embodiment. In the example shown in FIG. **12**, the amorphous conductive layer **134***d* is provided between the predetermined metal containing conductive layer **134***b* and the lower conductive layer **134***c*. However, the amorphous conductive layer **134***d* may be provided in an arbitrary position in the cap layer **130**.

According to the present embodiment, the same effect as the first, second and third embodiments can be achieved and a magnetic memory device equipped with a sufficiently reliable cap layer can be achieved.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. A magnetic memory device comprising:

a magnetoresistive effect element; and

a first layer provided on the magnetoresistive effect element,

wherein the first layer comprises:

a first crystal conductive layer having a crystal structure;

an amorphous conductive layer provided between the magnetoresistive effect element and the first crystal conductive layer and having an amorphous structure; and

a second crystal conductive layer having a crystal structure and provided between the magnetoresistive effect element and the amorphous conductive layer.

2. The device of claim **1**, wherein the amorphous conductive layer is formed of an amorphous alloy of a transition metal and a semimetal or an amorphous alloy of transition metals.

3. The device of claim **1**, wherein the magnetoresistive effect element comprises a first magnetic layer having variable magnetization, a second magnetic layer having fixed magnetization, and a nonmagnetic layer provided between the first magnetic layer and the second magnetic layer.

4. A magnetic memory device comprising:

a magnetoresistive effect element; and

a first layer provided on the magnetoresistive effect element,

wherein the first layer comprises:

a first crystal conductive layer having a crystal structure; and

an amorphous conductive layer which is a nonmagnetic layer, said amorphous conductive layer containing a main element identical to a main element contained in the first crystal conductive layer and having an amorphous structure,

wherein the amorphous conductive layer is provided between the magnetoresistive effect element and the first crystal conductive layer, and

wherein the first layer further comprises a second crystal conductive layer having a crystal structure and provided between the magnetoresistive effect element and the amorphous conductive layer.

5. The device of claim **4**, wherein the main element is selected from Ru, Pt, Ir, Pd, Au, W and Ta.

6. The device of claim **4**, wherein the amorphous conductive layer contains a noble gas element.

7. The device of claim **4**, wherein the magnetoresistive effect element comprises a first magnetic layer having variable magnetization, a second magnetic layer having fixed magnetization, and a nonmagnetic layer provided between the first magnetic layer and the second magnetic layer.

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